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Estimating the impact of reveals on the transmission heat transfer coefficient of internally insulated solid wall dwellings

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ABSTRACT

Internal wall insulation as a retrofit measure could help to reduce energy use and greenhouse gas emissions in many of the 6 million solid wall buildings in the UK. However during retrofit, junctions that are hard to deal with are often left uninsulated, increasing heat loss and surface mould growth risk at thermal bridges. Furthermore the effect of junctions, insulated or uninsulated is not properly taken into account in commonly used assessments of heat loss.

This paper presents a study on the impact of the junctions around openings, also called *reveals*, on the transmission heat transfer coefficient of internally insulated dwellings and a discussion on potential areas of improvement of common assessment tools for retrofit.

Findings showed that reveals account for the majority of the transmission heat transfer coefficient at junctions, that thicker wall insulation is not necessarily advantageous from a heat loss perspective, and that the transmission heat transfer coefficient at junctions per unit area of exposed elements was often higher than the reference value used in the UK.

1. Introduction

The transmission heat transfer coefficient of uninsulated buildings is dominated by the heat transfer through the plain elements of the building fabric. However, when buildings are insulated, the heat transfer through junctions can have a significant impact on the transmission heat transfer coefficient of a building [1]. This is particularly relevant in the case of solid wall buildings that have been internally insulated but are left without insulation at junctions, where a significant thermal bridge is created. However, the compliance calculations do not reflect this significant thermal bridging as the reference values are based on new build construction and as such underestimate the transmission heat transfer coefficient at junctions in existing solid wall buildings.

The aim of the study was to estimate the impact of reveals on the transmission heat transfer coefficient of typical solid wall dwellings in the UK, when insulated internally and to identify potential areas of improvement of common assessment tools for retrofit. Previous research has focused on the impact of the heat flux through junctions on the transmission heat flux of a building [2–5]. However, a more recent analysis of the impact of individual junctions on a mid-terrace has shown that window and door reveals account for the majority of the transmission heat transfer coefficient at junctions when junctions are left uninsulated [6].

A parametric analysis was undertaken for an end-terrace dwelling, taking into account a number of external wall thicknesses, internal wall insulation thicknesses and thermal conductivities. The impact of insulated and uninsulated reveals on the transmission heat transfer coefficient of an end-terrace is presented. These findings are then compared with findings from a previous mid-terrace analysis, in order to test the proposition more fully.

The transmission heat transfer coefficient at junctions was compared with the reference value defined in the UK's assessment tool for retrofit under the European Union Energy Performance of Buildings Directive (EPBD), to evaluate the validity of the reference value for retrofit.

Finally, this paper presents a discussion on how to estimate the meaningful maximum thickness of internal wall insulation. By meaningful is meant a specification which is most effective and safe from all relevant points of view. This study is based upon criteria of energy efficiency, but in assessing meaningful specifications of internal wall insulation other metrics such as moisture risk, embod-

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Nomenclature

λ	Thermal conductivity ($Wm^{-1}K^{-1}$)
U	Thermal transmittance ($Wm^{-2}K^{-1}$)
Ψ	Linear thermal transmittance ($Wm^{-1}K^{-1}$)
H_T	Transmission heat transfer coefficient (WK^{-1})
y	Transmission heat transfer coefficient at junctions per unit area of exposed elements ($Wm^{-2}K^{-1}$)

ied energy, floor space considerations and overall cost benefit may also be considered.

2. Methodology

The impact of reveals on the total transmission heat transfer coefficient of solid wall dwellings was assessed numerically. A parametric analysis was undertaken for an end-terrace dwelling, considering two external wall thicknesses, eight internal wall insulation thicknesses and a range of thermal conductivities for the wall insulation. The range of insulation thermal conductivity selected for the analysis characterises conventional insulation systems installed in the UK. These findings are then compared with findings from a previous mid-terrace analysis.

Also, the study focuses on the transmission heat transfer coefficient at junctions per unit area of exposed elements (**y-value**); in particular, it evaluates the validity of the y-value used as reference in the EPBD assessment tool for retrofit in the UK, RdSAP [7]. In the UK, the y-value is used to describe the impact of thermal bridges on the transmission heat transfer coefficient of a dwelling. For new dwellings, a conservative reference y-value (0.15 $Wm^{-2}K^{-1}$) is provided in part L1A of the Building Regulations [8]. Regarding retrofit of existing building, the relevant approved document, part L1B, states that “it is impractical to expect thermal bridge and temperature factor calculations” for compliance purposes [9]. However, RdSAP defines 0.15 $Wm^{-2}K^{-1}$ as a reference value [7]. The analysis shows that the y-value of the retrofitted buildings assessed in this study often exceeds the conservative y-value defined by RdSAP, used as a reference value in this analysis.

Following on from the analysis, there is a discussion on how to estimate the maximum thickness of internal wall insulation which it is worth installing in solid wall buildings, when all significant factors are taken into account (described as the meaningful maximum thickness).

2.1. Calculation method for the transmission heat transfer coefficient

The transmission heat transfer coefficient is the sum of the transmission heat transfer coefficient at the junctions of a dwelling and the transmission heat transfer coefficient associated with the plain elements of the building fabric [10].

The transmission heat transfer coefficient at junctions was calculated considering the junctions described below, which were classified as junctions between wall and openings (reveals), between two vertical elements and between vertical and horizontal elements:

- For the reveals, a *lintel*, a *sill* and a *jamb* (see Fig. 1) were analysed according to two levels of insulation: uninsulated reveals and insulated reveals with 20 mm-thick insulation. The lintels are limestone (λ = 1.7 $Wm^{-1}K^{-1}$) and their cross section is 150 mm (height) by 215 or 500 mm (width), depending on the thickness of the existing wall. For computational reasons, their length is the same as the width of the relative window/door. The internal sills are made out of timber, their height is 10 mm and the length is the same as the window width; the internal sill width is 20 mm more than the wall insulation thickness. The window frame is positioned 100 mm from the external surface.

- The junctions between two vertical elements analysed are:
  - Corners.
  - External wall and party wall (uninsulated party wall, see Table 1).
  - External wall and internal partition wall (uninsulated internal partition wall, see Table 1).

- The junctions between vertical and horizontal elements are the following:
  - Solid ground floor (uninsulated, see Table 1) and external wall.
  - Intermediate floor (uninsulated or insulated, see Table 1) and external wall.
  - Roof (insulated loft, see Table 1; uninsulated or insulated wall plate [11]) and external wall.
  - Roof and party wall (insulated loft, uninsulated party wall, see Table 1).
  - Roof and external gable wall (insulated loft, see Table 1).

The thermal properties of plane elements of the building fabric are shown in Table 1 (outside to inside, top to bottom). The U-values are calculated from BS EN ISO 6946 [12] and BS EN ISO 13370 [13].

Windows and doors are treated as adiabatic boundaries according to BR 497 [14]. For the calculation of the transmission heat transfer coefficient of plane elements, the windows are double glazed, with U_W = 2.3 $Wm^{-2}K^{-1}$ and the thermal transmittance of the doors is U_D = 1.8 $Wm^{-2}K^{-1}$.

The following assumptions were made in the analysis:

- The roof is insulated at ceiling level and its structure is not included (according to BR 497).
- The 2D software is not able to calculate three-dimensional corners and treats adjacent junctions (e.g. roof eaves over lintels) as separate.
- Inverted corners are not included.
- The floors and walls of the neighbouring dwellings are uninsulated (as in Table 1, considering an internal wall insulation thickness of 0 mm); the ceiling is slightly insulated (U_c = 0.35 $Wm^{-2}K^{-1}$).

The calculation of two-dimensional heat flux through the linear thermal bridges was carried out using the software Flixo® Pro v.5. The linear thermal transmittance Ψ ($Wm^{-1}K^{-1}$) of individual junctions was calculated according to BS EN 10211 [15]. The boundary conditions were set according to BR 497.

The transmission heat transfer coefficient of a case-study dwelling, H_T (WK^{-1}), was calculated according to BS EN ISO 13789 [10] using Eq. (1):

$$H_T = \Sigma_j U_j A_j + \Sigma_k \Psi_k L_k \quad j = 1\ldots n,\ k = 1\ldots m \tag{1}$$

Under the assumptions of the current study, H_T is the sum of the transmission heat transfer coefficient associated with n plane elements, where A_j (m^2) is the area of the element j, and the transmission heat transfer coefficient at m junctions, where L_k (m) is the length of the junction k.

The calculation of y ($Wm^{-2}K^{-1}$) was carried out according to SAP [7] applying Eq. (2), where the y-value is determined by the

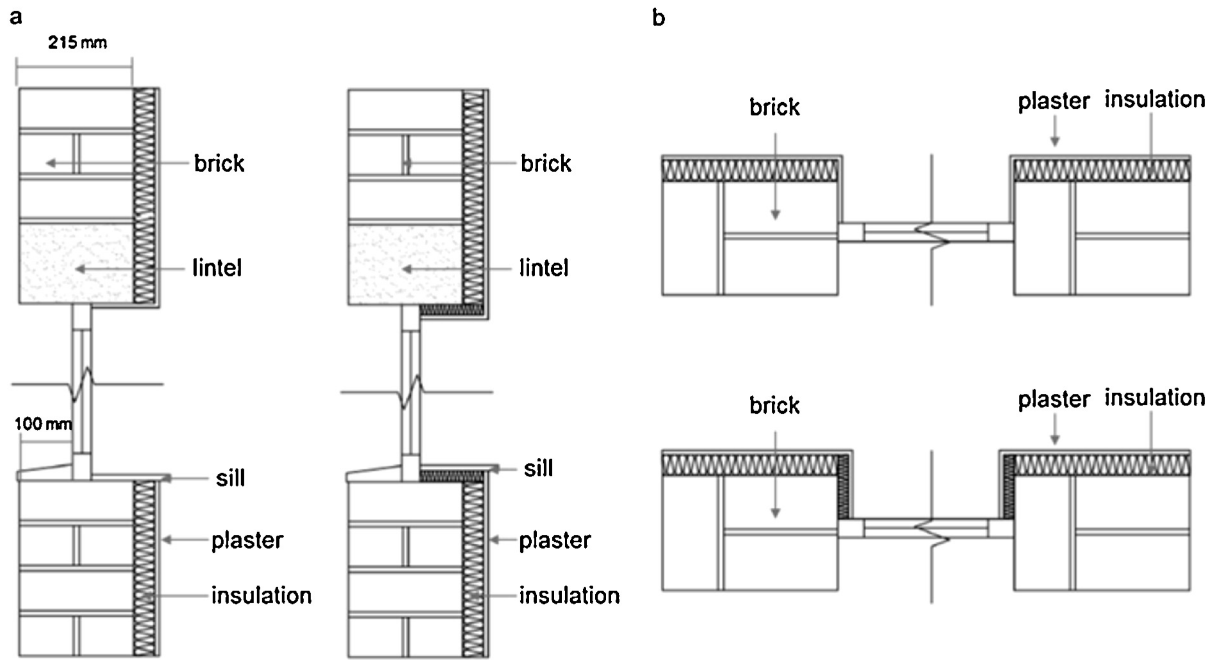

Fig. 1. (a) cross section detail of thin external wall, uninsulated (left) and insulated (right) reveals; (b) plan detail of thin external wall, uninsulated (top) and insulated (bottom) jambs.

Table 1
Plane elements of the building fabric: composition and thermal properties.

Element	Layer	Thickness (mm)	λ (Wm^{-1} K^{-1})
External wall/external gable wall	Brick	215; 500	0.770
	Internal wall insulation (IWI)	0; 20; 40; 60; 80; 100; 120; 140	0.026 (low) – 0.043 (high)
	Plaster	8	1.2
Roof (insulated loft)	Insulation batt	88	0.038
	Insulation batt between joists (joist fraction 7.2%)	80	0.038 (insulation batt); 0.13 (joists)
	Plasterboard	12.5	0.25
Solid ground floor	Timber flooring	20	0.28
	Concrete	150	2.3
Intermediate floor	Floorboards	12	0.13
	Oriented strand board	9	0.13
	Un-ventilated air layer	100	0.56 (air layer);
	Plasterboard	12.5	0.25
Party/partition wall	Plaster	8	1.2
	Brick	215 (party wall) 105 (partition wall)	0.770
	Plaster	8	1.2

transmission heat transfer coefficient at junctions divided by the total area of external elements of a dwelling, A_{exp} (m^2):

$$y = \frac{\sum_k \Psi_k L_k}{A_{exp}} \quad (2)$$

The calculated y-value was then compared with the reference value in RdSAP.

2.2. Case study

A typical end-terrace dwelling, identified as representative of pre-1919 English dwelling stock [16], was used in the analysis; the end-terrace has been selected as our primary case study as the majority of junctions are considered. The end-terrace is also compared with a mid-terrace of the same size. The dwellings dimensions are detailed in Table 2. The size and geometry of individual openings are derived from a Victorian sash window [17], characteristic of pre-1919 dwellings.

Table 2
Dimensions of case study dwellings.

	End-terrace	Mid-terrace
Width	6.25 m	6.25 m
Length	8.9 m	8.9 m
Height	5.7 m	5.7 m
Storeys	2	2
Openings perimeter	50.8 m	50.8 m
Openings area	17.4 m^2	17.4 m^2
Area of exposed elements (A_{exp})	233.23 m^2	182.5 m^2

Fixed values for the thermal transmittance of floors, roofs and openings are used in the analysis, considering all the building elements upgraded to comply with UK's building regulations (Table 1).

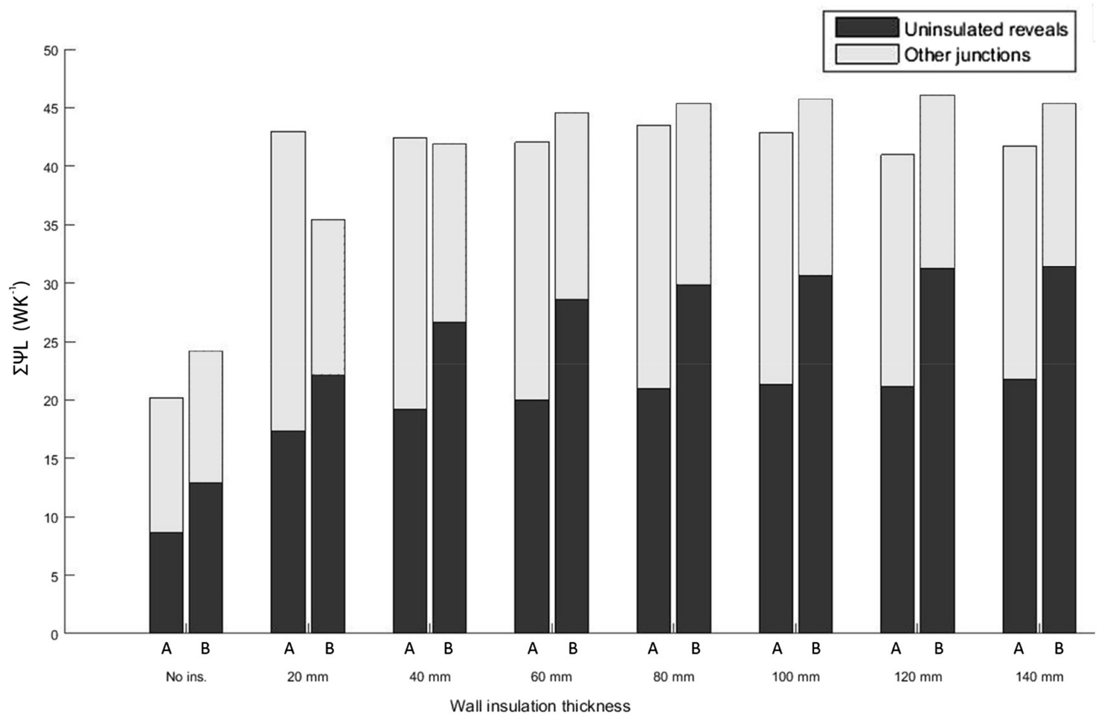

Fig. 2. Transmission heat transfer coefficient at junctions in an end-terrace with (a) thin and (b) thick external walls: contributions of uninsulated reveals (black) and other junctions (grey). $\lambda_{insulation}$ λ_{IWI} = 0.026 Wm^{-1} K^{-1}.

3. Results and discussions

3.1. Impact of reveals on the transmission heat transfer coefficient at junctions

The linear thermal transmittance of each individual junction was multiplied by the length of the corresponding junction and the contribution of reveals to the total transmission heat transfer coefficient at the junctions was assessed for two wall thicknesses (215 mm and 500 mm), as a function of wall insulation thickness (Fig. 2).

It was found that for both external wall thicknesses, the junctions showing the highest transmission heat transfer coefficient are the reveals, in particular jambs and lintels. For thin walls, uninsulated reveals account for 40–52% of the transmission heat transfer coefficient at junctions, whereas for thick walls they account for 53–69%. Fig. 2 shows the results related to an insulation thermal conductivity of 0.026 Wm^{-1} K^{-1}.

Uninsulated reveals have the biggest impact on the transmission heat transfer coefficient at junctions in the end-terrace dwelling for both thin walls with a minimum wall insulation thickness of 100 mm and in case of thick walls at all wall insulation thicknesses.

When reveals are insulated, the transmission heat transfer coefficient at reveals is reduced by more than two-thirds. As a consequence, this reduces the impact of reveals on the transmission heat transfer coefficient at junctions, so that the reveals can now account for 19–34% of the transmission heat transfer coefficient at junctions in case of thin walls and 43–58% in case of thick walls.

3.2. Impact of reveals on the transmission heat transfer coefficient of a dwelling

The initial transmission heat transfer coefficient of an end-terrace with uninsulated thin external walls is 328 WK^{-1}. In case of thick external walls, the existing wall has a higher resistance to heat loss and the initial total transmission heat transfer coefficient is 229.5 WK^{-1} (Fig. 3); therefore, the benefit of insulating the plane elements reduces and the reduction of transmission heat transfer coefficient in the case of thick walls was lower than in the case of thin walls.

When the walls are insulated, uninsulated reveals contribute to 6–16% of the transmission heat transfer coefficient of the end-terrace dwelling for a thin external wall and 11–21% for a thick external wall. On the other hand, when reveals are insulated, their contribution to the total transmission heat transfer coefficient is between 3% and 7% for thin walls and between 4% and 12% for thick walls.

The transmission heat transfer coefficient of an end-terrace was assessed as a function of wall insulation thickness, wall thickness and insulation level at reveals. The analysis considered a range of thermal conductivities typical of conventional insulation systems in the UK (e.g. phenolic foam, mineral wool or woodfibre).

The gradient of the transmission heat transfer coefficient curve tends to zero at high insulation thickness (Fig. 3); for example, there is a small difference on the transmission heat transfer coefficient for wall insulation between 120 mm and 140 mm (2.5 WK^{-1} for thin walls and 4 WK^{-1} for thick walls).

Highly insulated dwellings with uninsulated reveals could have the same transmission heat transfer coefficient as dwellings with lower wall insulation thickness but insulated reveals. For example, 80 mm of wall insulation, with insulated reveals, presents a higher reduction of transmission heat transfer coefficient than 140 mm of wall insulation but uninsulated reveals. This is valid for both thin and thick external walls and within the range of insulation thermal conductivities considered. This difference can be even greater in buildings with a higher proportion of reveals to external wall area such as in mid-terrace dwellings; in a mid-terrace with thick walls, 140 mm of internal wall insulation and uninsulated reveals can deliver a similar transmission heat transfer coefficient to 20 mm of wall insulation with insulated reveals [6].

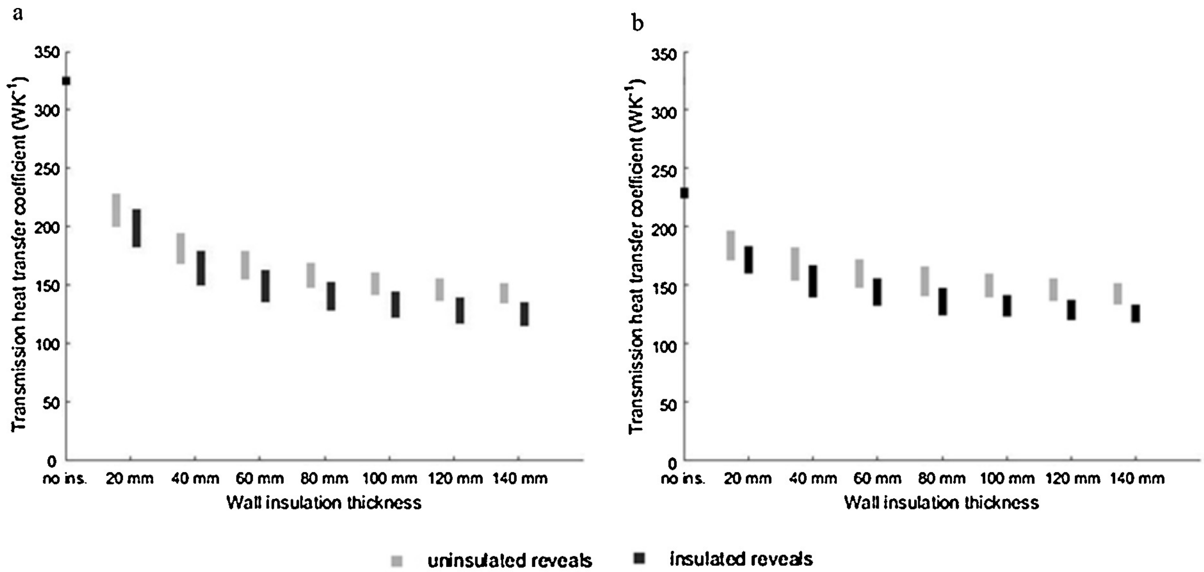

Fig. 3. Transmission heat transfer coefficient in an end-terrace with (a) thin external walls and with (b) thick external walls. The bar represents the range of insulation thermal conductivity considered (λ_{IWI} = 0.026–0.043 Wm^{-1} K^{-1}).

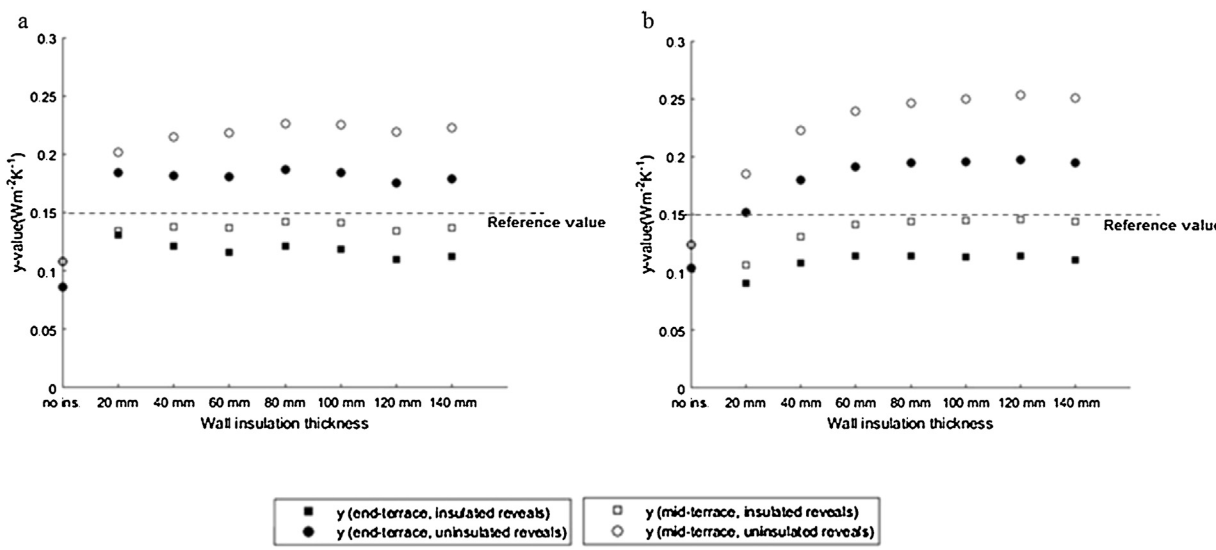

Fig. 4. y-value of end-terrace and mid-terrace with (a) thin and (b) thick external walls (λ_{IWI} = 0.026 Wm^{-1} K^{-1}).

3.3. Y-value

The y-value was compared to the reference value for RdSAP, y = 0.15 Wm^{-2} K^{-1} (Fig. 4), as the reference value should represent the worst case scenario regarding heat loss at junctions. This means that all calculated y-values should fall below the reference value. However, it was found that the y-value falls below the reference value only when reveals are insulated. In the end-terrace, y-values of around 0.2 Wm^{-2} K^{-1} are reached when reveals are uninsulated; in the mid-terrace the y-values are higher, reaching 0.25 Wm^{-2} K^{-1} when reveals are uninsulated, and close to 0.15 Wm^{-2} K^{-1} when insulated.

In both cases (thin and thick external wall), the calculated y-value is often above the reference value when reveals are uninsulated; hence, the reference value does not represent the worst case scenario for both the end-terrace and the mid terrace.

3.4. Estimation of meaningful internal wall insulation thickness

The maximum reduction of transmission heat transfer coefficient in an end-terrace with thin and thick external walls was 63% and 44% respectively. However, the transmission heat transfer coefficient reduces asymptotically as function of insulation thickness, leading to a negligible reduction of heat loss at high insulation thicknesses. Such small improvements indicate that there is a point at which increasing the wall insulation thickness does not have any impact on the overall heat loss of a dwelling.

This section opens a discussion about possible methods for the selection of meaningful thicknesses for internal wall insulation. The selection should take into consideration other variables such as embodied energy, cost and mould growth risk if the estimation is to be acceptable for overall energy impact, moisture safety and practicality. For example, a method for selecting the wall thickness could be based on the reduction of the transmission heat transfer coefficient caused by an improvement of the wall thermal resis-

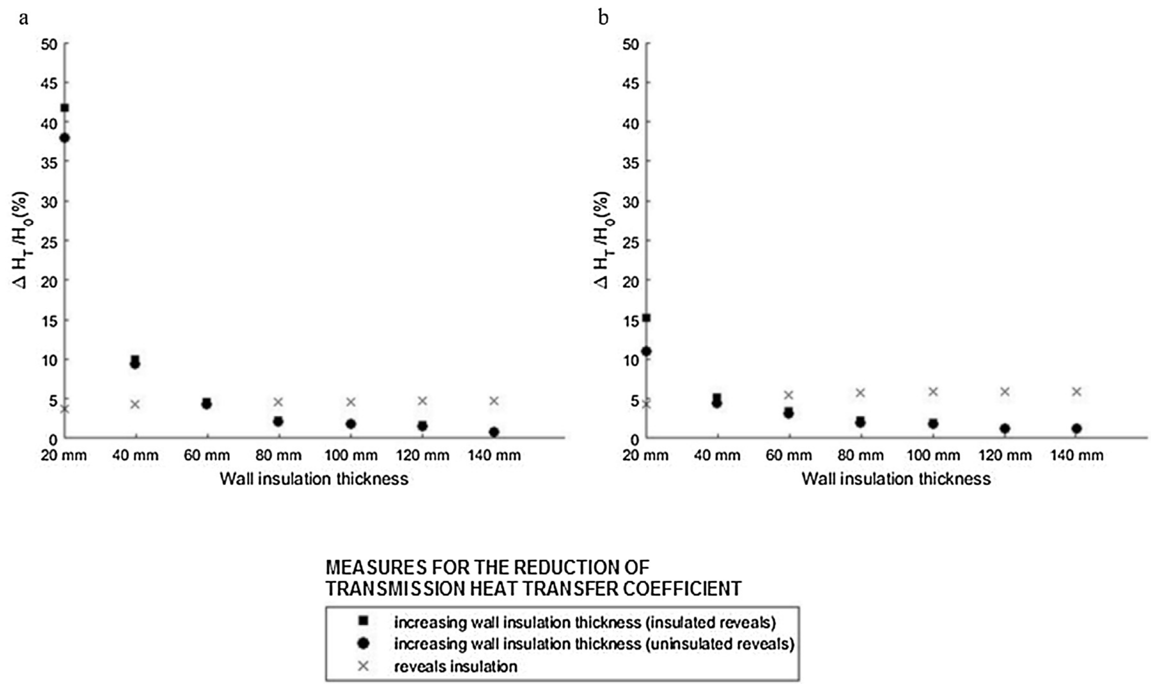

Fig. 5. Percentage reduction of transmission heat transfer coefficient in an end-terrace with (a) thin external walls and with (b) thick external walls (λ_{IWI} = 0.026 $Wm^{-1} K^{-1}$).

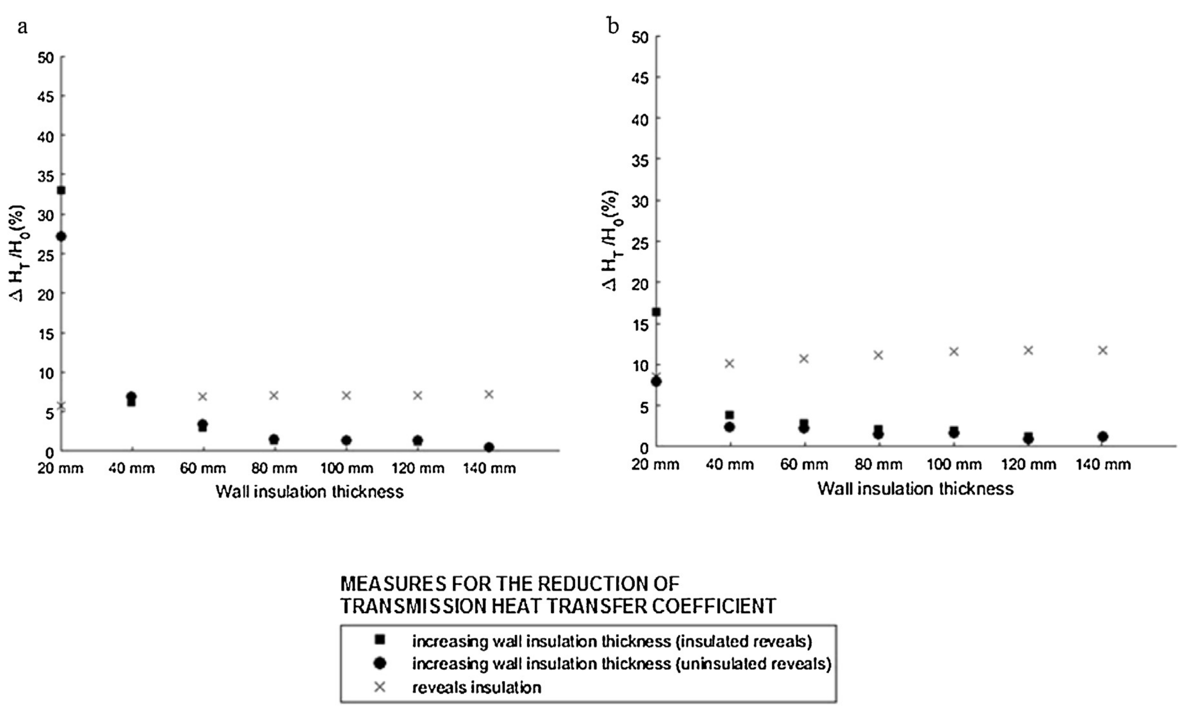

Fig. 6. Percentage reduction of transmission heat transfer coefficient in a mid-terrace with (a) thin external walls and with (b) thick external walls (λ_{IWI} = 0.026 $Wm^{-1} K^{-1}$).

tance when adding 20 mm of wall insulation, ΔH_T. The reduction is calculated as a percentage of the initial transmission heat transfer coefficient for an uninsulated dwelling, H_0 (e.g. the percentage reduction at 40 mm of internal wall insulation is the difference between the transmission heat transfer coefficient at 20 mm and 40 mm of wall insulation, ΔH_T, divided by the transmission heat transfer coefficient at 0 mm of wall insulation, H_0). This increase in wall insulation thickness should cause an acceptable reduction of the transmission heat transfer coefficient H_T. Applying the same method to reveals, it is possible to assess when reveals should be insulated. The study shows that adding insulations at reveals can cause a significant percentage reduction of transmission heat transfer coefficient. Fig. 5 shows a comparison between the reduction of transmission heat transfer coefficient given by the two measures for an end-terrace where the insulation has a thermal conductivity at the lower end of the range. Here, increasing the wall insulation thickness from 40 mm to 60 mm has the same impact on the transmission heat transfer coefficient as insulating the reveals.

In a mid-terrace dwelling (Fig. 6), the percentage reduction associated to the effect of reveals insulation, considering the insulated dwelling ('reveals insulation'), could be ten times bigger than the reduction associated to increasing the insulation thickness by 20 mm.

Although the two dwellings have the same floor area, the results are different primarily because of the proportion of reveals to wall area. The study has shown that measures such as insulating the reveals can deliver a more significant reduction of transmission heat transfer coefficient than increasing the insulation thickness. There is a point when the increase of insulation thickness seems to have little or no effect on the transmission heat transfer coefficient. Therefore, a threshold should be defined, so to avoid cost-inefficiency and waste of resources. One way of defining the threshold could be using an EPBD assessment tool such as the Standard Assessment Procedure, considering the embodied energy of insulation or simply by drawing an analogy with a lightbulb:

- *Assessment tool*: the Standard Assessment Procedure allows the calculation of a Design Fabric Energy Efficiency rate of a dwelling and compares it to a target value, calculated around a *notional dwelling* which has the same dimensions as the assessed dwelling but thermal properties defined by the UK building regulations [8]. The concept of notional dwelling does not exist in retrofit, but it could be defined; however, the parameters describing the dwelling should be selected taking into account the technical issues related with internal wall insulation. In particular, mould growth risk should be the key factor when identifying the thermal properties of the walls and thermal bridges; also, the properties related to thermal bridges (i.e. the reference y-value) should account for the space constraints and technical limitations highlighted in the current study.
- *Embodied energy of insulation*: the maximum meaningful insulation thickness could be decided based on the relationship of the embodied energy of insulation and the total heat loss reduction due to the measure during the insulation lifetime.
- *Lightbulb analogy*: an analogy could be drawn between the percentage reduction of the transmission heat transfer coefficient and the power of an incandescent light bulb. This could make the determination of maximum thickness more understandable and therefore meaningful for non-technical people.

4. Conclusions

The study aimed at estimating the impact of reveals on the steady-state transmission heat transfer coefficient and identifying potential areas of improvement of common assessment tools for retrofit.

The analysis considered variations of wall thickness, internal insulation thickness, insulation thermal conductivity and two levels of insulation at reveals. The analysis is presented through a case study, where typical English end-terrace and mid-terrace dwellings were analysed and compared.

It was ascertained that reveals account for the majority of transmission heat transfer coefficient at junctions; in the study, they were responsible for up to 69% of the transmission heat transfer coefficient at junctions and up to 21% of the transmission transfer coefficient in an end-terrace. The thicker the existing wall, the higher the transmission heat transfer coefficient through reveals.

It was also found that the y-value of an end-terrace with uninsulated reveals falls usually above the conservative reference value defined by the assessment tool for retrofit, RdSAP [7], $0.15\,\mathrm{W m^{-2} K^{-1}}$; the analysis showed y-values of up to $0.2\,\mathrm{W m^{-2} K^{-1}}$. Higher y-values (reaching $0.25\,\mathrm{W m^{-2} K^{-1}}$) were found in a mid-terrace dwelling, indicating that y-values in internal wall insulation are sensitive to the building form and particularly the proportion of reveals to exposed area.

The transmission heat transfer coefficient at junctions was found to increase with thicker wall insulation; as a result, the transmission heat transfer coefficient profile flattens at higher wall insulation thicknesses. Therefore, there is little additional benefit of applying extra internal wall insulation after a certain threshold. Insulating the junctions can be a more appropriate solution than increasing the insulation thickness or reducing its thermal conductivity. The findings opened a discussion about possible methods for the selection of acceptable wall insulation thicknesses to be applied on a solid wall dwelling. Criteria based on appropriate notional dwellings (with low mould growth risk), embodied energy and a light bulb analogy were discussed, which could be the background method for the development of a simple decision making tool for the retrofit of solid wall dwellings.

This analysis is based on a fixed thermal transmittance of floors, roof, openings and existing wall and on a fixed position of openings (for the calculation of linear thermal transmittance). These factors have an influence on the impact of reveals on the overall heat loss of a dwelling, suggesting that internal wall insulation needs to be assessed as part of a whole house approach. Finally, the study concerns the impact of reveals on the steady-state transmission heat transfer coefficient of a dwelling. The analysis does not consider the transient nature of realistic climatic conditions and thus the thermal mass of the walls, which can strongly affect the thermal behaviour of heavyweight buildings.

Further research will include the analysis of mould growth risk in internally insulated dwellings.

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References

[1] CIBSE, Environmental Design – CIBSE Guide A, CIBSE, 2010.
[2] P. Schild, P. Bloem, An effective Handling of Thermal Bridges in the EPBD Context, 2010, ASIEPI.
[3] D. Mumovic, I. Ridley, T. Oreszczyn, M. Davies, Condensation risk: comparison of steady-state and transient methods, Build. Serv. Eng. Res. Technol. 27 (3) (2006) 219–233.
[4] W. Feist, B. Kaufmann, T. Loga, R. Pfluger, M. Ratzlaff, J. Schnieders, P. Simons, Protokollband n.32. Faktor 4 auch Bei Sensiblen Altbauten: Passivhauskomponenten + Innendaemmung, Passivhaus Institut, Darmstadt, 2005.
[5] A.C. Andersson, Folgen zusätzlicher Wärmedämmung – Wärmebrucken feuchteprobleme, Wärmespannungen, Haltbarkeit Bauphysik 2 (4) (1980) 119–124.
[6] V. Marincioni, H. Altamirano-Medina, N. May, Parametric study on the impact of thermal bridges on the heat loss of internally insulated buildings, Energy Procedia 78 (2015) 889–894.
[7] BRE, SAP 2009 The Government's Standard Assessment Procedure for Energy Rating of Dwellings. No. March, BRE, 2011.
[8] Approved Document L1A – Conservation of Fuel and Power in New Dwellings, HM Government, 2013.
[9] HM Government, Approved Document L1B – Conservation of Fuel and Power in Existing Dwellings, No. October, HM Government, 2015.
[10] BSI, ISO 13789 – Thermal Performance of Buildings – Transmission and Ventilation Heat Transfer Coefficients – Calculation Method, BSI, 2007.
[11] Zero Carbon Hub, Closing the Gap Between Design and as-Built Performance. No. March, Zero Carbon Hub, 2014.
[12] BSI, BS EN ISO 6946 Building Components and Building Elements—Thermal Resistance and Thermal Transmittance—Calculation Method, BSI, 2007.
[13] BSI, BS EN ISO 13370:2009 Thermal Performance of Buildings—Heat Transfer via the Ground—Calculation Methods, BSI, 2009.

[14] T. Ward, C. Sanders, BR 497 Conventions for Calculating Linear Thermal Transmittance and Temperature Factors, BRE Press, 2007.
[15] BSI, BS EN ISO 10211:2007 Thermal Bridges in Building Construction—Heat Flows and Surface Temperatures—Detailed Calculations, BSI, 2007.
[16] E. Oikonomou, M. Davies, A. Mavrogianni, P. Biddulph, P. Wilkinson, M. Kolokotroni, Modelling the relative importance of the urban heat island and the thermal quality of dwellings for overheating in London, Build. Environ. 57 (2012) 223–238.
[17] E. Denison, G.Y. Ren, The Life of the British Home, Wiley, 2012.